Faculty of Social and Life Sciences
Department of Biology

Katrin Wahlström

Sediment Requirements for Freshwater Pearl Mussel (*Margaritifera margaritifera*) Recruitment

Sedimentkraven för Rekrytering hos Flodpärlmussla (*Margaritifera margaritifera*)

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Supervisor: Björn Arvidsson
Martin Österling
Examiner: Eva Bergman
Serial Number: 06:89

Karlstads universitet 651 88 Karlstad
Tfn 054-700 10 00 Fax 054-700 14 60
Information@kau.se www.kau.se

Abstract

The sediment requirements for freshwater pearl mussel (Margaritifera margaritifera) recruitment, in 18 rivers in the counties of Västra Götaland, Örebro, Värmland and Västmanland in Sweden, were investigated. The top 4 cm of sediment in the rivers was analysed in terms of size, distribution and organic compound within the fine sediment. The aims of the study were to determine whether there is a relation between sediment particle size compound and freshwater pearl mussel recruitment as well as between organic compound in fine sediment and recruitment of mussels. The study shows that there is a significant difference in the amount of organic silt between non-recruitment and recruitment sites with a higher percentage of organic silt in recruitment sites. There is also a legible difference between the amounts of silt per sample between non-recruitment sites and recruitment sites where there was significantly more silt in sediment samples of non-recruitment sites. With the exception of fine sediment, no significant difference was found between non-recruitment and recruitment sites regarding size class distribution.

Sammanfattning

Sedimentkraven för rekrytering hos flodpärlmussla (Margaritifera maragaritifera) i 18 svenska vattendrag belägna i Västra Götalands, Örebro, Värmlands och Västmanlands län undersöktes. Vattendragens översta 4 cm sediment analyserades gällande storlek, fördelning och organisk sammansättning i finsedimentet. Målen med studien var att fastställa huruvida det finns förhållanden mellan sedimentets partikelstorleksammansättning och rekrytering av flodpärlmussla samt mellan finsedimentets organiska sammansättning och rekrytering av musslor. Studien visar en signifikant skillnad i organiskt finsediment mellan icke-rekryteringsplatser och platser med rekrytering där rekryteringsplatser hade högre procentuell andel organiskt finsediment. En signifikant skillnad påvisades också mellan andel finsediment per sedimentprov där sedimentprov från icke-rekryteringsplatser innehöll en högre procentuell andel finsediment. Förutom gällande finsediment påvisades ingen signifikant skillnad i sedimentets storleksdistribution mellan rekryterings- och icke-rekryteringsplatser.

Introduction

The freshwater pearl mussel *Margaritifera margaritifera* (L.) is an ancient mussel species, which can reach an age of 200 years and more (Lundstedt 1995). Freshwater pearl mussel populations can be found in many parts of the northern hemisphere with the largest frequency of populations in the north part of Europe (WWF 2005). In rare cases the mussel can grow valuable pearls that has fascinated people for centuries and led to widespread mussel fishing throughout Europe. The species has declined and disappeared from approximately 50 percent of its extension during the first decades of the last century and it has disappeared from a third of the Swedish rivers where it could be found one hundred years ago. It can today be found in approximately 400 rivers of Sweden although reproduction does not take place in most of these (WWF 2005). The freshwater pearl mussel is since first of January 1994 protected in Sweden (Eriksson et al. 1998) and the pearl fishing has radically declined. The threat towards this ancient mussel species today consists of a complex network of factors including acidification, pollution, siltation, decline of host fish and impacts from water flow regulation (WWF 2005). The plight of the freshwater pearl mussel is severe to the extent it is consequently considered vulnerable in the red list of IUCN, meaning that most or all populations are decreasing, as well as it is listed under Annex II of the EU Habitats Directive (Wells et al. 1983, Bauer 1988, Young et al 2002).

The freshwater pearl mussel belongs to the family *Margaretiferidae* which is ranked under the order *Unionidae*, class *Bivalvia*, phylum *Mollusca*. The life cycle of the mussel is of a complex nature. They generally mature at 10 – 15 years when their length has exceeded 65 mm. Reproduction takes place during the summer when sperm is released into the water through the male’s exhalant siphon and inhaled by the filtering female to fertilise her eggs (Smith, 1979). After a period of approximately 4 weeks the eggs have matured into small larvae, known as glochidia, which are then released into the water by the female. After release, the glochidia are dependent on reaching the gill tissue of a host fish, which is specifically the family *Salmonidae*, in Sweden the native salmon, *Salmo salar*, or the brown trout, *Salmo trutta*, are used. The glochidia life cycle is spent on the host fish gill as a parasite where the glochidia gets all the nutrients for survival through absorption from the gill (Bergengren 2000, Skinner et al. 2003). During the parasitical stage the glochidia increase 6 times its original length and develop into a young mussel (Cranbrook 1976). When the glochidia is large and mature enough to exist independently, after approximately 7 – 11 months (Eriksson et al 1998), it excysts, drops off and bury into the sediment, where it lives interstitially in the river substrata and remains buried, for about 5 years, until large enough to withstand the conditions of the flowing water (Eriksson et al 1998, Jones et al 2005, Wells et al. 1983). By that stage the mussel has reached a size of approximately 10 mm. The mussel will from now on sit securely anchored with up to two thirds of its length buried in the substrata, siphons exposed to the flowing water, siphoning the water for food particles. Water enters the inhalant siphon, flows over the gills and exits through the exhalant siphon. Food particles entering with the water are transferred to digestive grooves (Moorkens, 1999). The food consists of plankton and microscopic particles of dead plants and animals (Ulvholt 2005).

The freshwater pearl mussel is generally found in clear, well oxygenated, calcium deficient, fast flowing rivers with clean bottoms and plenty of host fish. The water is generally oligotrophic and low in nutrients with a pH of 7.5 or less and overall low conductivity (WWF 2005). The river has to be deep enough during summer, not to dry out or induce low oxygen levels or heat stress. The river also has to be deep enough not to freeze during winter. Presence of mussels of a large age-span is a good indicator of a healthy river where interaction between species is undisturbed (Gittings et al 1998, Skinner et al 2003).

The plight of the freshwater pearl mussel is complex and the reasons for its decline are many. In Sweden the pearl fishing was the most threatening cause to pearl mussel populations until the beginning of the 20th century. During the first half of the last century many populations were destroyed during river management to create floating stretches for timber as the forestry branch expanded. Also, during this time, hydropower plants were built with the result of dams, water flow regulations and miles of suitable habitat destroyed. The hydropower plants also constitute a threat for the host fish migration, which the freshwater pearl mussel is dependant upon. Now the major threats are of a different nature, although still influenced by humans (Eriksson et al 1998, Young et al 2001). In recent times the main threats to the survival of the freshwater pearl mussel consist of a loss of suitable riverine habitats, through dredging and other land-use activities, sedimentation and siltation from poor agricultural and silvicultural management. Even engineering work such as fishery management, bridge and dam constructions and road management creates various amounts of fine silt in the water environment. The fine silt can clog the interstitial part of the river sediment, hindering the important flow of water and oxygen to this area, crucial for the survival of post parasitic mussel juveniles (Moorkens 2000, Box & Mossa 1999, Cosgrove et al 2000, Lydeard 2004, Bauer 1988, Buddensiek et al 1993, WWF 2005, Skinner 2003, Geist, 1997, Ulvholt, 2005). The most distinctive worrying feature of the remaining freshwater pearl mussel populations is the lack of juveniles found in most of these populations. Hence locations where there are signs of juvenile recruitment are particularly important for the viability of the species (Cosgrove & Hastie 2001, Ziuganov et al 1994). This paper is focusing on the effect of sediment structure on freshwater pearl mussel recruitment. As a filter feeder the freshwater pearl mussel is dependant upon fine organic matter for its survival but too much silt could clog the crucial habitat of juvenile mussels and thus prevent successful recruitment. Crucial is also a certain amount of sediment allowing the mussel to burrow in thus become firmly imbedded in the substratum. Knowledge of sediment structure requirements would help conservation of this highly threatened ancient species and enable the assessment of future river management policies (Lewis and Riebel 1984, Hastie et al 2000). The early post-settlement stages of the freshwater pearl mussel are extremely sensitive and are thought to have very specific sediment requirements (Young & Williams 1983, Buddensiek et al 1993).

This study reports on the sediment requirements for recruitment of freshwater pearl mussels in 18 different rivers in Sweden. Focus lies on the amount of organic and inorganic fine sediment in sites with functional current recruitment compared with sites where there is no sign of recruitment within the freshwater pearl mussel populations. The aim is to determine whether there is a connection between presence of juvenile mussels and size of sediment particles respectively organic compound of the fine sediment. The hypothesis of the study is that adult mussels are tolerant to a wider range of physical conditions and that consequently mussel sites, with no signs of recent recruitment, are previously colonised riverbeds that gradually have become unsuitable for recruitment of young mussels due to habitat degradation. Thus this study contributes to conservation knowledge as it aims to unearth suitable sediment requirements for future protection and recovering of the severely imperiled freshwater pearl mussel.

Methods

Site selection

14 of the rivers selected for the study are included in the LIFE project. Life Nature is a fund that supports the implementation of the EU's Habitat Directive (http://europa.eu.int/ life/ home.htm). The LIFE project of freshwater mussels is a project aiming to develop and test a method to improve habitats for the freshwater pearl mussel in 21 rivers in Southern Sweden (www.wwf.se\flodparlmussla). The other 4 rivers were chosen because of their similarity to the rivers included in the LIFE project and their suitable location to get as many replicates as possible of rivers with, respectively without, recruitment.

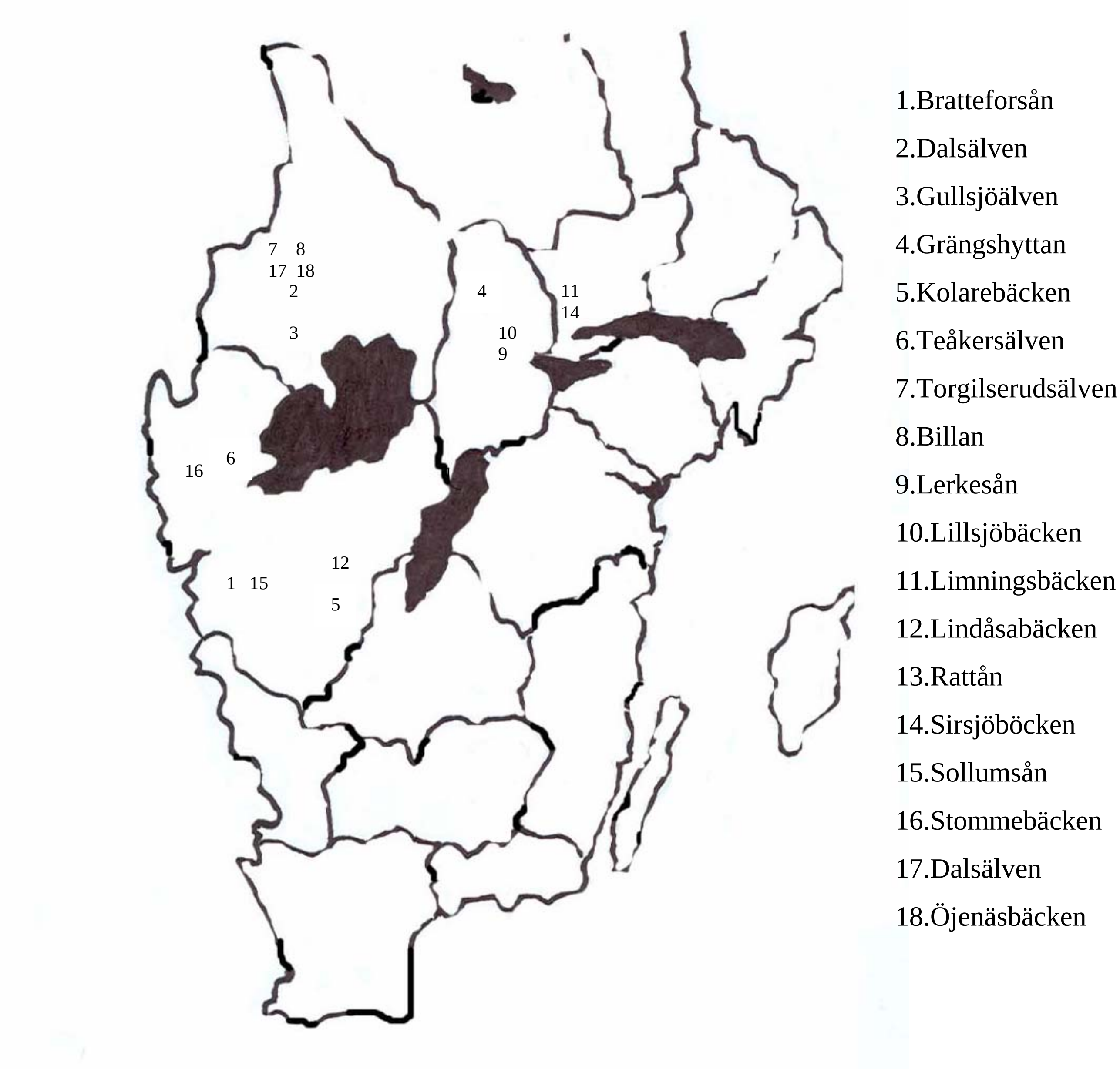

Figure 1. Location of sites

Field data collection

The sites were areas of 30.1 – 93.4 m^2, one site in each of the rivers. Within the sites 6 – 14 quadrates of 1 m^2 were randomly placed. Mussels and samples of sediment were collected from within the quadrates. All mussels visible or found by excavating the top 10 cm were collected and age determined by measuring ligament and shell growth. Any description of the status of a mussel population must refer to its current ability to recruit juveniles (Cosgrove et al 2000). In this study a recruitment site was determined by the age of the youngest mussel found. A site containing mussels below or at the age of 10 years was considered a recruitment site. All live mussels were returned to the river as soon as they were measured. Two 3.7 cm sediment cores were collected from each quadrate from the top 4 cm of substrate.

Sediment analysis

The top 4 cm of sediment in 18 different rivers were analysed in terms of size, distribution and organic compound within the fine sediment. In this study sediment smaller than 1 mm is categorized fine sediment whilst silt is sediment smaller than 0.063 mm. In the laboratory sediment cores were washed with 5400 ml of water, wet-sieved in a nested sieve measuring 0.075 mm. To record amount of silt per sample, as well as amount of organic silt, sediment smaller than 0.075 mm was filtered through Whatman filters that afterwards were dried at 105 ºC for 24 hours and thereafter weighed and burnt at 505 ºC for 3 hours and weighed again after cooling. Sediment left in the 0.075mm sieve was emptied onto metal containers, dried at 105 ºC for approximately 24 hours, dry-sieved in a tower of decreasing geometric mesh sizes measuring 11.2 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm. The fractions retained on each sieve were weighed and the proportion of each particle size class was calculated. The two smallest fractions, >0.125 mm and >0.063 mm, were burnt at 505 ºC for 3 hours. The burnt fractions cooled and were weighed again.

Statistical analysis

Two-tailed student's t-test were used to determine any differences in mean values between the two groups – non-recruitment site respectively recruitment site, regarding numerous sediment qualities. A p-value < 0.05 is considered significant. Values for variances and standard errors were also calculated.

Results

Table 1. Description of mussel populations. *Maximum dimension to closest mm.

No.	River	No. of mussels found	Length of smallest mussel*	Age of youngest mussel (years)	Recruitment site
1	**Bratteforsån**	16	68	14	No
2	**Dalsälven**	16	84	31	No
3	**Gullsjöälven**	19	89	30	No
4	**Grängshyttan**	7	61	17	No
5	**Kolarebäcken**	14	64	24	No
6	**Teåkersälven**	20	71	13	No
7	**Torgilserudsälven**	14	87	30	No
8	**Billan**	13	38	9	Yes
9	**Lerkesån**	33	39	9	Yes
10	**Lillsjöbäcken**	5	41	8	Yes
11	**Limningsbäcken**	17	47	10	Yes
12	**Lindåsabäcken**	116	44	8	Yes
13	**Rattån**	62	37	10	Yes
14	**Sirsjöbäcken**	1	40	10	Yes
15	**Sollumsån**	58	30	5	Yes
16	**Stommebäcken**	43	38	10	Yes
17	**Älgån**	28	8	2	Yes
18	**Öjenäsbäcken**	100	21	5	Yes

Over all 11 rivers were considered to have mussel recruitment whilst in 7 rivers no mussel at or under the age of 10 was found. The numbers of mussels found in each river varied from 1 to 116. 7 to 20 mussels were found in non-recruitment rivers whilst the numbers varied from 1 to 116 in recruitment rivers. Average length varied from 61 to 89 mm in non-recruitment rivers and from 8 to 47 mm in recruitment rivers. The age of youngest mussel found in the rivers varied from 13 to 31 years in non-recruitment rivers and between 2 to 10 years in recruitment rivers (table 1). The dry sieved material (table 2) was divided into 4 category groups; larger than 11.2 mm, smaller than 11.2 mm to larger than 4mm, smaller than 4 mm to larger than 1 mm and fine sediment, i.e. smaller than 1 mm to larger than 0.063 mm (figure 1). The result in the first size category average percentage varied between 10.80 % and 16.18 % in non-recruitment rivers and between 9.12 % and 23.57 % in recruitment rivers. In the second size category average percentage varied between 18.46 % to 34.14 % in non-recruitment rivers. In recruitment rivers the result was a variation of averages between 14.96 % and 38.46 % in the second size category. In the third size category non-recruitment rivers varied in averages from 26.68 % to 33.34 % and recruitment rivers from 22.99 % to 43.39 %. Regarding the category fine sediment the average percentage in non-recruitment rivers varied between 14.65 % and 30.53 %. In recruitment rivers the averages varied between 11.62 % and 34.94 %. The result of dry sieving did not show any significant differences between the two groups in any of the size categories (table 2, figure 2 and 3).

Table 2. Average sediment distributions, of sediment sizes from >11.2->0.063mm, calculated as percentage.

No.	River	> 11.2 mm	> 8 mm	> 4 mm	> 2 mm	> 1 mm	> 0.5 mm	> 0.250 mm	> 0.125 mm	> 0.063 mm
1	Bratteforsån	25.74	9.93	19.40	15.77	12.74	8.77	4.91	2.08	0.66
2	Dalsälven	22.92	7.50	10.96	11.90	16.18	9.11	11.09	7.92	2.42
3	Gullsjöälven	20.81	9.76	16.84	17.26	15.71	11.22	5.30	2.22	0.88
4	Grängshyttan	17.88	11.38	22.75	18.64	14.69	9.27	3.76	1.29	0.34
5	Kolarebäcken	13.93	10.40	16.12	17.21	13.73	10.56	9.16	6.99	1.90
6	Teåkersälven	29.65	9.48	17.72	15.88	10.80	7.73	5.41	2.72	0.61
7	Torgilserudsälven	23.81	9.11	24.30	16.58	12.81	6.99	3.89	2.09	0.42
8	Billan	25.56	12.67	20.23	15.55	12.45	8.61	3.43	1.21	0.29
9	Lerkesån	9.62	6.48	13.27	19.82	23.57	17.38	6.65	2.40	0.81
10	Lillsjöbäcken	22.28	10.74	15.54	14.38	13.01	11.14	8.86	3.33	0.72
11	Limningsbäcken	26.98	11.64	17.71	13.80	11.43	9.99	5.73	2.24	0.48
12	Lindåsabäcken	25.41	12.10	19.36	16.50	11.30	7.72	4.88	2.18	0.55
13	Rattån	27.11	5.71	9.25	11.39	11.60	12.84	12.92	6.53	2.65
14	Sirsjöbäcken	24.07	13.68	24.78	16.74	9.12	4.84	3.79	2.34	0.64
15	Sollumsån	12.34	8.48	22.54	23.00	12.40	8.15	7.44	4.52	1.13
16	Stommebäcken	15.40	9.56	19.00	21.19	19.64	10.29	3.23	1.30	0.39
17	Älgån	16.76	6.83	14.06	17.30	18.92	15.24	7.42	2.83	0.64
18	Öjenäsbäcken	26.37	7.62	14.99	18.64	15.54	9.42	4.37	2.21	0.84
	p-value	0.71	0.95	0.66	0.48	0.68	0.26	0.98	0.50	0.59

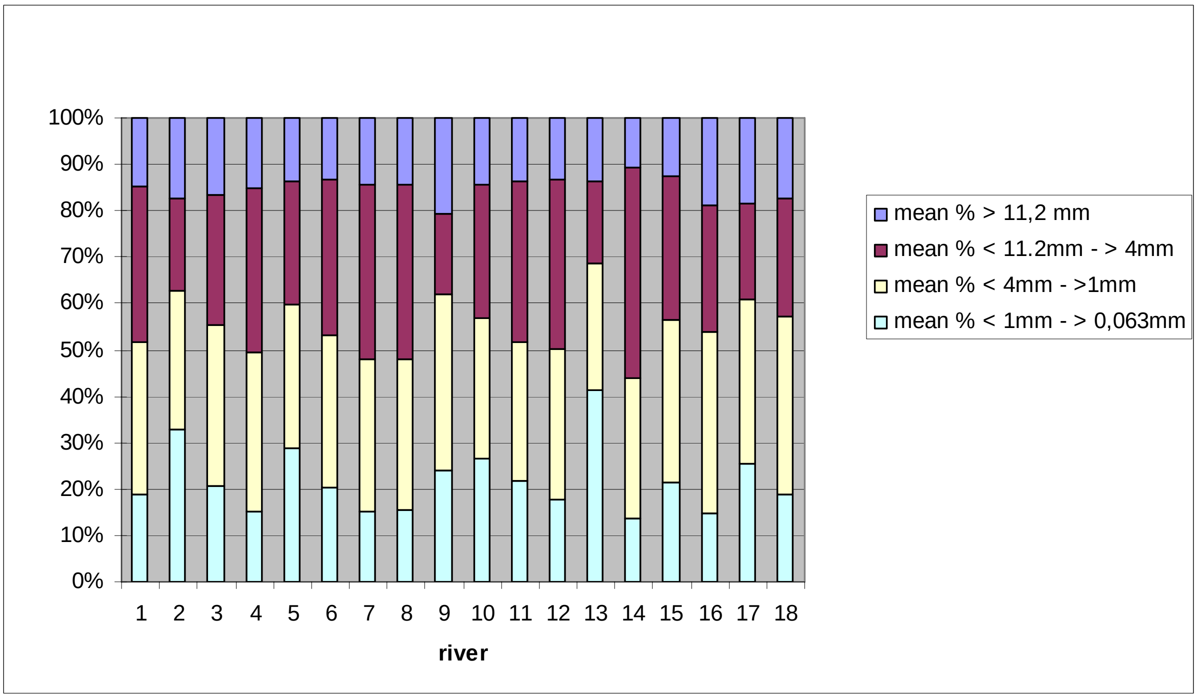

Figure 2. The sediment distribution in the 18 rivers investigated.

‘**Figure 3.** Distribution of fine sand (< 0.125 mm - > 0.063 mm) in non-recruitment respectively recruitment sites. Standard error bars shown on top of blocks.

The most significant difference between the two groups in this study is the difference in organic silt (table 3, figure 4). In non-recruitment rivers the average percentage varied between 5.62 % and 16.69 % whilst the result in recruitment rivers was a variation of averages between 11.57 % and 36.67 %. A student’s t-test showed a significant difference between the two groups with a p-value smaller than 0.05.

Table 3. Description of percentage amount of organic silt and average amount of silt per sample. Average percentage of organic silt (rounded off to 2nd decimal). Average amount of silt (g) per sample (rounded off to 3rd decimal).

No.	River	Amount organic silt (%)	Amount silt/sample (g)
1	Bratteforsån	10,35	0.060
2	Dalsälven	11,35	0.032
3	Gullsjöälven	16,41	0.005
4	Grängshyttan	5,62	0.116
5	Kolarebäcken	11,82	0.018
6	Teåkersälven	11,31	0.043
7	Torgilserudsälven	16,69	0.013
8	Billan	13,29	0.019
9	Lerkesån	15,17	0.028
10	Lillsjöbäcken	19,38	0.005
11	Limningsbäcken	20,65	0.004
12	Lindåsabäcken	32,18	0.007
13	Rattån	24,63	0.019
14	Sirsjöbäcken	28,09	0.005
15	Sollumsån	13,36	0.021
16	Stommebäcken	36,67	0.007
17	Älgån	11,57	0.020
18	Öjenäsbäcken	20,36	0.026
	t-value	7.07	3.77
	p-value	1.55E-08	0.004

Figure 4. The mean percentage of organic silt in non-recruitment respectively recruitment sites. Standard error bars shown on the top of blocks.

The second most prominent difference between the two groups is the difference in amount of silt per sediment sample (table 3, figure 5). In non-recruitment rivers this amount varied between 0.005 g and 0.116 g per sample. The recruitment sites had a significantly lower amount of silt per sample in average, varying between 0.004 g and 0.028 g per sample. A student's t-test gave the result of a p-value smaller than 0.05.

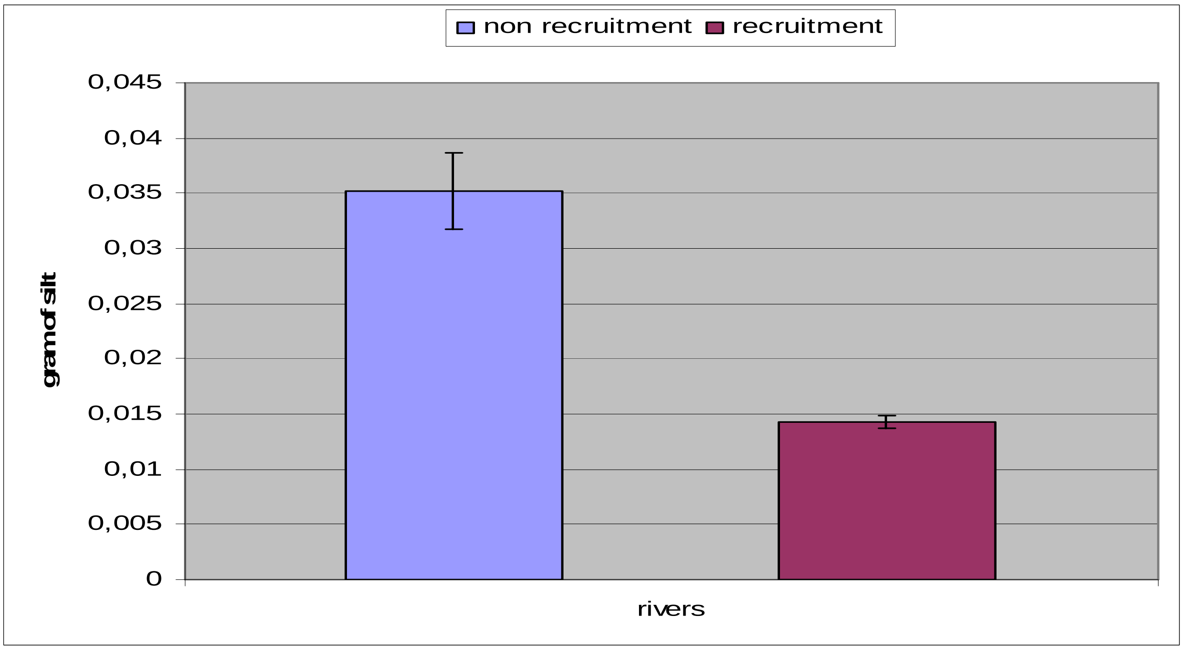

Figure 5. Average amount of silt per sediment sample (vol = 86.02ml) when washed through Whatman-filter. Standard error bars shown on top of blocks.

Discussion

The physical microhabitat requirements of freshwater pearl mussel are nowadays thoroughly studied. Normally, freshwater pearl mussels live partly buried, or as juveniles totally buried, in well-aerated sand and gravel in fast flowing, clean rivers (Cosgrove & Harvey 2003). In 1990 the US Environmental Protection Agency cited sediments as the number one pollutant of rivers in the United States (Box & Mossa 1999). It is well known, and has been for a long time, that siltation has strong impacts on benthic fauna and flora and that mussels, in particular, can be affected through multiple mechanisms, of fine particles. Silt can lodge between grains of sediment and reduce interstitial flow of water thus diminish suitable habitats for juvenile mussels. Silt can also clog the gills of mussels and thereby interfere with filter feeding. Heavy siltation reduces light hindering photosynthesis thus reducing food items for both mussel and host fish (Box & Mossa 1999, Buddensiek et al 1993, Munn & Meyer 1988). It has been reported in Sweden before that small numbers of adult and no juveniles have been observed in silty substrata (Björk 1962). The results of this study coincide with earlier studies on the subject. Thus adult freshwater pearl mussels may be tolerant to silty conditions whilst that kind of substrata may be wholly unsuitable for juveniles (Hastie et al 2000). The result showing a higher percentage of organic silt in recruitment sites is yet another certificate pointing in the same direction. In these sites the juvenile mussels will be able to feed on the organic silt whilst in non-recruitment sites the inorganic silt will clog the suitable habitats of young mussels. Several studies have identified river management and engineering work such as pipe laying, hydro-power work, bridge support, dam construction and maintaining, forestry and fishery management to have serious impact on freshwater pearl mussels and that such engineering work can directly implicate in the decline of populations of the species (Box & Mossa 1999, Valovirta 1990, Killeen et al 1998, Cosgrove et al 2000). The decline of host fish because of degradation of suitable spawning areas is also a result of siltation. Mussels, who are known to be able to filter up to 50 litres of water per day, could through the filtration help to clarify rivers to the benefit of species such as salmon and trout (Cosgrove & Hastie 2001, Skinner et al 2003). Therefore protecting rivers from siltation would not only benefit the imperiled mussels but also the economically, and host wise, important fish populations of the rivers.

Earlier studies have shown that if the amount substrata constitutes of 25 % or more of fine sediment (< 1 mm), the interstitial pockets will get clogged and the chances of juvenile mussel survival seriously decrease (Geist 1997, Ulvholt 2005). However, in this study, there are both non-recruitment and recruitment sites with substrata consisting of more than 25 % fine sediment. The result showing an eloquent similarity between non-recruitment and recruitment sites regarding sediment size distribution could be interpreted as a distribution, regarding sediment size, excluding silts, being a suitable habitat for freshwater pearl mussels with a perfect mixture of sand, gravel and cobble. Perhaps the delimitation at 25 % is too low or not at all a limiting factor in the case of the rivers of this study. The striking conformity between the two groups regarding sediment distribution may be a sign of their suitability for hosting mussels. The result shows that the non-recruitment sites of this study have suitable substrata in terms of sediment distribution. Removal of siltation as a cause of the previous decline in mussels may bring these sites closer to consideration of re-introduction attempts.

Research on associations between sediments and mussels is more credible if data for both elements are of high quality. However, collecting sediment from river substrata can be more difficult than one would think. The ultimate sediment sample collected is a perfect core where nothing of the sediment escapes back into the river. To achieve such samples, in a constantly changing medium, one would need highly technical equipment, which would involve considerable expense. However, in this study, a considerable amount of replicates per site were collected and therefore the results should be considered reliable. Regarding mussel data, sampling bias is to be considered since the majority of juvenile mussels are likely to be missed, when counting mussels in the field, even by experienced surveyors (Cosgrove & Harvey 2003).

Although one of the most worrying features in the conservation of the mussel species is that so few rivers seem to show any signs of sustainable recruitment of young mussels, it is important, not only to focus on the sites where recruitment is functional, but on all freshwater pearl mussel populations. The species can live to be one hundred years and rivers that are currently suffering from unsuitable recruitment habitats should still be considered with the hope that one day the causes of this state will have been removed. The fertility of freshwater pearl mussels is strikingly independent of environmental factors, which would imply that populations could recover if the causes of decline were to be removed (Bauer 1988). The results of this study demonstrate that suitable river sediment is vital for sustainable freshwater pearl mussel recruitment. Thus, regarding future conservation, this will be of important consideration when assessing suitability of mussel conservation sites, applied on either existing populations or areas for introduction.

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